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EFFECT OF TE PRECIPITATES ON THE PERFORMANCE OF CdZnTe (CZT) DETECTORS

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Measurements taken at the National Synchrotron Light Source allowed us to make detailed comparisons of the microscale responses and infrared (IR) microscopy images of CdZnTe Frisch-ring x-ray and gamma-detectors. The data conclusively showed that local deteriorations of electron-charge collection and the device's response to x-rays fully correlate with the presence of Te precipitates as revealed in the IR images. These data offer the first experimental evidence of the material property limiting the energy resolution of CZT gamma-ray detectors.

$Cd_{1-x}Zn_xTe$ is an attractive material for fabricating crystals for x- and gamma-ray detectors. With its large band-gap (i.e., the energy gap determines its leakage current), detectors produced from the material function well at room temperature, while the high atomic numbers of its elements impart high quantum efficiency (i.e., sensitivity). In principle, detectors are simple devices that directly convert the charge pairs generated by ionizing- and gamma-radiation into electrical signals. These advantages, combined with very good resolution, make CZT detectors suitable for a wide range of purposes, such as imaging devices for nuclear medical imaging, detectors for measuring the movement of radioactive materials, monitors to prevent the diversion of stored nuclear weapons and components, and applications in astronomy.

Authors (from left) Giuseppe Camarda, Gabriella Carini, and Aleksey Bolotnikov

Unfortunately, structural defects, such as twins, dislocations, inclusions, grain- and tilt-boundaries result in crystals of low quality, which severely limit the detectors' performances. Several groups have characterized CZT detectors at the microscale, thereby allowing detailed investigations of their spatial responses. These measurements delineated the detrimental effects of grain boundaries and twins, but were unable to describe the physical mechanisms responsible for the carrier trapping. Further, the role of dispersed Te inclusions and precipitates within the single-crystal CZT volumes remained unclear. Recently, by developing a unique measurement facility affording an order-of-magnitude improvement in spatial resolution, we obtained unequivocal evidence correlating regions where the detector's performance was degraded with the presence of dispersed Te-rich inclusions.

This correlation between Te precipitates, visible in the IR images of crystals, and the deterioration of the devices' responses was measured for several 1-mm thick planar CZT detectors. The original CZT crystals, grown by the Modified Vertical Bridgman method, were supplied by Yinnel Tech., Inc. To obtain the measurements, the detectors were mounted inside a standard eV-Products device holder and irradiated from the cathode side. The output signals were readout and processed using standard spectroscopy electronics, including a charge-sensitive preamplifier, a shaper, and a MCA card to collect pulse-height spectra. To study local variations in the device's response, x-ray scans were performed at the NSLS X12A beamline employing beams of different sizes; the smallest was slightly less than 10x10 μm^2. For each X-Y position of the x-ray beam, pulse-height spectra were collected, and the peak positions, which are proportional to the total collected charge, were evaluated using a Gaussian fit. We plotted the findings from the scans as two-dimensional maps of the devices' responses (**Figure 1**)

Comparing the IR micrographs and x-ray scans (**Figure 2**), the Te precipitates in the IR images clearly correspond to the dark spots in the x-ray maps where the device's response drops off by up to 50% of its average value. Furthermore, several similar measurements for different thin devices fabricated from CZT crystals grown by different techniques showed, for the first time, a 100% correlation between the locations of the precipitates and the areas of the detector with poor performance.

In contrast to randomly distributed single-level traps, precipitates can be considered as extended local defects with a very high local concentration of trapping centers. In this case, an unpredictable number of charges will be trapped, and the amount of trapping cannot be corrected with current techniques. Here, the fluctuations in charge loss are proportional to the total number of such defects encountered by the electron cloud. Moreover, any electric-field distortions around these defects also can contribute to dispersing the collected charges and to degrading the spectroscopic performance.

In the past, CZT detectors underwent x-ray, gamma-ray, and alpha-particle scans to investigate the uniformity of their responses; the sizes of the beams used in those measurements were 100 µm or larger. This investigation clarified that the size of the x-ray beam used for the scans is an important factor in determining the ability to spatially resolve the effects of isolated Te-rich precipitates. **Figure 3** presents four maps of the same area on a device evaluated with different spatial resolutions to simulate different beam sizes. The original x-ray map, measured with 10 µm steps in both directions with a beam of 10x10 µm² unambiguously shows the degraded regions due to 10-20 µm diameter Te inclusions. They are not as clear in the 20x20 µm map. No precipitates were observed with a 100x100 µm² beam, and the crystal seems fairly uniform in the 200x200 µm² map. The earlier mapping measurements obtained by many groups using larger beams led the CZT detector community to incorrectly assume that isolated Te precipitates did not adversely affect a detector's quality. Our new measurements, offered in this paper, allow researchers to easily discern the effects of precipitates on electron trapping, and they highlight the critical need to address the presence of isolated Te precipitates and aggregates of them within single-crystal CZT detectors.

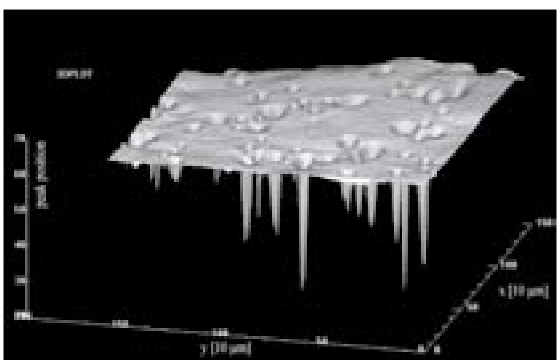

Figure 1. Three-dimensional view of an x-ray map. The scan was performed by using a 10x10 µm² sized, 30 keV beam.

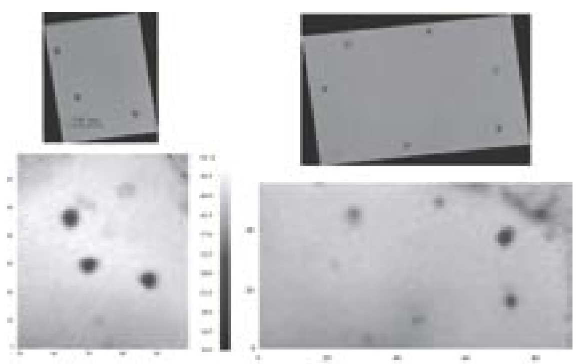

Figure 3. X-ray maps from the same area of the device evaluated with different spatial resolutions: 10x10 µm², 20x20 µm², 100x100 µm², and 200x200 µm².

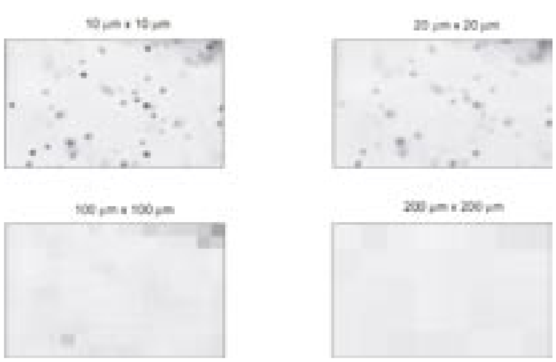

Figure. 2. Examples of correlations between x-ray and IR transmission maps measured for a 1 mm thick CZT planar device. The scans were performed by using a 10x10 µm² sized, 85 keV x-ray beam. In some cases, the typical triangular shapes of precipitates are recognizable in the x-ray maps.